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ABSTRACT

Sequential relationships between Stroop color-word stimuli were explored in a random discrete-trials manual response design. Posttrial availability of an interfering response was indicated by a subsequent reduction of reaction time when that response became appropriate. Previous evidence for suppression of competing responses is probably artifactual. A second experiment indicated two sources of interference in the Stroop task: (a) the number of highly available competing responses and (b) the individual strength of each competing response. (Author)

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CONFLICT RESOLUTION IN THE STROOP COLOR-WORD TASK

An Investigation of Inhibitory Processes in Cognitive Control [1]

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In common experience, deliberate attention to one source of information often seems to reduce the ability to process information from a different source. This phenomenon is demonstrated experimentally in the "cost-benefit analysis" developed by Posner and Snyder (1975a,b): Allocation of attention to one source, or "channel", results in a reaction-time "cost" to other channels, relative to when attention is not committed to any particular channel. In most theories, selective attention is conceived as directly facilitating a given channel; "costs" thereby result from reduced availability of this "attentional mechanism" or "attentional capacity" to all unattended channels. Alternatively, one can conceive of selective attention through specific inhibition of undesired channels. In this case, processing costs would possibly be limited to such "disattended" channels, with little cost to other unattended channels previously uninvolved. Inhibition at the neuronal level is a physiological fact, and suppression effects are acknowledged in the conditioning and verbal learning literatures. The present problem concerns the demonstration of inhibition at a different level, that of "cognitive control".

In 1935, J. Ridley Stroop demonstrated a phenomenon which has since become widely known as the "Stroop Effect": It takes longer to identify the color of a stimulus if that stimulus itself is a written word which names a color other than that

in which it is written. For example, the time to respond "red" to a red stimulus will be greater if it is the word "GREEN" than if it is the word "HOUSE", the word "RED", or a simple red color patch. Subjects are apparently unable to "filter out" the irrelevant word information; when this information leads to activation of a response which is incompatible with the correct color-response, interference occurs (Morton, 1969; Keele, 1972). Nevertheless, subjects generally do respond to "Stroop" words, albeit with some delay and increase in errors; they do not sit frozen in perpetual indecision about what response to make. The question is then how a subject, faced with the activation of two competing responses, manages to emit one and only one, usually correct, response. This is really two questions: The first, which will not be dealt with here, is how the subject decides which response is correct; the second is how this decision is implemented. With regard to the latter question, two possibilities immediately suggest themselves: One possibility is that the correct response is directly facilitated, through selective allocation of some resource, or perhaps by increasing its activation strength substantially above that of the competing response. The alternative possibility is that the incorrect response is directly suppressed, thereby allowing the correct response to proceed automatically.

The suppression hypothesis suggests that the suppressed competing response might become temporarily less available

than other responses. If that suppressed response then becomes appropriate on an immediately following trial, reaction time should be longer than if the newly appropriate response was previously uninvolved. In accord with this prediction, Dalrymple-Alford and Budayr (1966) found that total color-naming time down a list of Stroop words was slowest when the color-name of each item was identical to the interfering word-name of the item immediately above it--E.g. the word "GREEN" written in red ink, preceded by the word "RED" written in blue. Their conclusion was, in fact, that suppression of each word-name made its retrieval as the subsequent color-name more difficult. Sichel and Chandler (1969) basically replicated these results using voice-key reaction times to stimulus pairs, in which they varied the relation of the first Stroop word to the second. However, careful inspection of this design leads one to suspect that neither of these studies really provides support for the suppression hypothesis. In the Sichel and Chandler study, subjects were instructed to report the colors of both simultaneously present stimuli, in order. Since a voice key was used, recorded latencies were necessarily of only the first response emitted, of each pair. Thus, effects of relationships between pairs of Stroop words would seem to reflect "backward", rather than "forward" interference. The results of Dalrymple-Alford and Budayr, and those of Sichel and Chandler, may then be explained by a

tendency to look ahead to the next item while trying to respond to the current one. Analogously, it is common knowledge that people reading prose aloud tend to "read ahead". It may well be that seeing a new color which is named by the current word-activated response makes it very difficult to decide which of the competing responses is really appropriate.

In an experiment completed last summer, six subjects were shown singly-presented Stroop stimuli on an inline display controlled by a PDP-9 computer. Each stimulus remained present until one of four keys, corresponding to red, green, blue or yellow, was pressed. Immediately upon response, a new, randomly-selected stimulus replaced the previous stimulus, until completion of a block of 100 trials. Each subject was tested individually over six days on a total of 8000 Stroop color-naming trials (per S).[2] The reaction times were catagorized according to the relationship of each stimulus to the stimulus occurring in the immediately preceding trial.

It was expected that the present experiment would simply replicate Dalrymple-Alford and Budayr, and Sichel and Chandler, but under more rigorous conditions. Use of a discrete-presentation method obviously precludes backwards interference from subsequent stimuli. Much to our surprise, the opposite result was obtained: responses were faster when they were identical to the previous interfering response than in in the control condition in which the response was totally

unrelated to the preceding stimulus. The 9-msec difference, although small, was significant at $p < .02$, and generally consistent across subjects. The finding of a small facilitation, rather than the predicted suppression effect, is quite consistent with a facilitatory mode of cognitive control. If an interfering response is not suppressed, but rather "ignored" while the appropriate response is facilitated, then it is reasonable to suppose that it will remain relatively available over some duration, during which its residual activation strength may be added to a subsequent activation by a color. These results have been further confirmed by a similar analysis of unpublished Stroop task data collected in another context by Steven Keele: A somewhat larger facilitation effect was found, over a sample of 32 subjects. Post-trial availability of the interfering response seems firmly established.

Since stimuli were presented randomly, other possible relationships to preceding trials could also be analyzed. The most surprising result came from the condition in which the current interfering response, activated by the word, was identical to the preceding correct response, activated by the previous color. Note that this relationship is the converse of that in the condition used to test the suppression hypothesis. It is certain that a color response, once emitted, remains very highly available, as evidenced by the very

powerful "repetition effect" when that same response is again appropriate. So, one would certainly expect great difficulty when a response just emitted is identical to the response that now interferes with the new appropriate response --the previous response should reinforce the tendency to make the current competing response, thereby increasing the interference. It therefore came as a shock to find that this condition was also faster than the control condition, in which the current stimulus bore no direct relationship to the preceding one. The 20-msec difference was highly significant, $p < .01$. The analysis of the larger sample collected by Keele again confirmed the general pattern of results.

The most direct conclusion at the time seemed to be that greater availability of a response can not only facilitate that response, but may also facilitate the <u>rejection</u> of that response. This proposition would seem wholly incompatible with passive activation models, such as Morton's (1970) "Logogen" model, in which the bias to emit a response should directly reflect its summated strength of activation. However, an alternate, less radical explanation could be proposed. It is possible that the assumed "control" condition, in which the stimulus was unrelated to the preceding stimulus, was in fact yielding greater interference through a somewhat different mechanism. Since we have already established that

both the appropriate and interfering responses from the previous trial remain highly available, they may then contribute to the new set of activated responses from which the subject must choose the correct response. When a current interfering response is identical to a prior response, the total number of activated responses to choose from is reduced. When neither the previous word nor the previous color are related to either current word or color, the most interference may reflect the largest number of currently competing responses (four, counting the correct one).

The latter explanation originally seemed inadequate on two counts. First, the post-trial strengths of prior response activations would be expected to be somewhat diminished during the new trial; one would expect the subject's greatest difficulty to be the rejection of the powerful activation by the current word. Thus it seemed unlikely, although not impossible, that introduction of a fourth, less compelling alternative should have more of an effect than contributing to the strength of the primary source of interference. Secondly, this argument suggests that subjects should be even faster when the current trial and preceding trial together involve only <u>two</u> responses covertly as well as overtly--e.g. the word "RED" written in <u>green</u>, preceded by the word GREEN written in <u>red</u>. While this condition was also faster than the "unrelated" condition, the degree of facilitation was <u>less</u> than that in the condition

where only the current word and the previous color matched.

Nevertheless, further tests seemed warranted by the drastic implications of the initially preferred conclusion. In a recently completed series of experiments an attempt was made to replicate this result by manipulations within trials, rather than between trials. In each trial, subjects first saw a warning signal which was either a plain "plus" symbol or a color-related prime. Some subjects received colors as primes, others received words. The prime could be related to either the color or the written meaning of the subsequent Stroop stimulus, or an irrelevant color response could be primed. An intertrial interval of several seconds probably minimized intertrial effects, which were at any rate balanced by randomization with regard to priming conditions. The results were clearcut: Priming an unrelated response and priming the interfering word-activated response <u>both</u> produced longer latencies than the truly "neutral" condition in which no response was primed. In fact, there was here little difference between these two priming conditions. Thus, the pronouncement that increasing the availability of a response may facilitate its rejection appears to have been made prematurely. Rather, the correct interpretation seems to be that there are two possible sources of interference with color-naming: the <u>number</u> of competing responses, and the <u>strength</u> of any particular competing response. Whether one

source is more potent than the other in a given situation may depend on a fortuitous interplay of factors which may or may not be of theoretical importance, but are at any rate, obscure.

In conclusion, the study of priming and sequential relationships in the Stroop task has revealed the following: Competing response tendencies are not completely suppressed in order to make an appropriate overt response. In fact, irrelevant word-activated responses remain highly available, as conventional facilitatory models of attention might predict. This continued availability may result in subsequent facilitation of that response when appropriate. On the other hand, as secondary analyses suggest, continued availability may also increase interference when still inappropriate, by adding to the set of currently competing responses. In either case, the results contradict previous results from multiple presentation of Stroop stimuli, reinforcing the suspicion that the "suppression" effects are really an artifact of the tendency to "look ahead" to subsequent stimuli.

To end on a positive note, I would like to argue that inhibition as a mode of cognitive control has only been deprived of its previous support--it cannot be rejected. First, suppression may only be partial, to an extent that the appropriate response can be made unhampered, leaving the irrelevant response still more available than in its baseline,

"rest" state. Results such as those in the present experiment could thus be obtained. Secondly, it would undoubtedly be naive to assume that only one mode of cognitive control exists throughout the complex human cognitive system. Even if inhibition is unimportant in the Stroop conflict, it is quite possible that it is a dominant mode of control in other kinds of processing. Indeed, one would think that inhibition of a selected few troublesome channels would often be more efficient than allocating some limited resource to a small set of channels and thereby depriving oneself of other processes which could otherwise be operating simultaneously. For this reason, I am optimistic that similar paradigms employing different sorts of tasks could succeed in demonstrating inhibitory effects. I am quite certain that demonstration of inhibitory cognitive control would add immeasurably to our understanding of mental processes.

Besides, we all know what Freud had to say about conflict resolution, don't we?

FOOTNOTES

[1]A portion of this research was done in partial fulfillment of the requirements for the Master of Arts degree, awarded to the author by the University of Oregon in September, 1975. For further theoretical discussion and experimental details, please refer to the resultant Thesis (Neill, 1975).

[2]Previous pilot work had suggested that extensive practice with key-press responding, which yields cleaner data, might substantially reduce the size of the Stroop Effect. This contrasts with other studies which have found negligible practice effects using vocal responding, and probably reflects the ability to by-pass verbal mediation of the stimulus-response association. Therefore, on days 2-5, each block of 100 color-naming trials was alternated with blocks in which subjects were instructed to ignore the color of the stimulus, and to respond to the word meaning instead. This manipulation was intended to maintain a strong association between written word and manual response, without which Stroop conflict would not be expected. The word-naming latencies provide little information, except for one interesting incidental observation: Practiced key-press responding to the color of the Stroop words seems to concurrently develop color-interference with word-responding. Past studies using vocal responding have found such a so-called "reverse-Stroop Effect" only by degrading the word legibility, or otherwise peripherally biasing perception to the disadvantage of the word-information relative to the color-information.

One further complication of the design lies in the inclusion of "congruent" ("RED" written in red, for example) and "neutral" (nonword, of the form "0000") stimuli on Days 1 and 6. These stimuli were included in order to verify the existence, and persistence, of Stroop interference. Performance on Days 1 and 6 did not appear to differ from Days 2-5 with regard to the categories of response.

As noted in the text, data collected by Keele generally replicated the obtained pattern of results. This latter study did not involve as complicated a design, and so it seems safe to conclude that the specific peculiarities of the former study are not relevant to the collected data.

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